INTERPLAY OF SYMMETRIES IN QUANTUM FIELD THEORIES AND ITS CONSEQUENCES IN PARTICLE PHYSICS

Summer Project Report for the session 2012-2013

Submitted by

Devashish Singh
2nd year, B. Sc. (Hons.) Physics, CMI.
(KVPY Reg. No. : SB – 1111222)

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Advisor: Dr. K. P. Yogendran

Department of Physics,

IISER, Mohali.
**Project Report**

The statement of the problem of physics of elementary particles is pretty simple and straightforward: What is matter made of, at the most fundamental level—the smallest scale of size? and to understand its intrinsic properties (e.g. mass, charge, spin etc.). To describe its observational behavior, all we need to know is the *actors* i.e. the different type of particles, existing in the *drama* i.e. Nature; and the *dialogues* between them i.e. how they interact with each other. This is no trivial task. We need to formulate a model, guided by certain general principles, in particular, quantum mechanics and relativity; to describe these fundamental interactions consistently. These lie in the domain of *the smaller and the faster* where QFT is the best fitting description of Nature.

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<td><strong>Quantum Field Theory</strong></td>
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There is a wide difference between a *type of mechanics* and a *particular force law*. The former tells how to use the latter to determine motion. Therefore, to correctly understand elementary particle dynamics, we try to model a set of force laws within the context of QFT. Here, symmetry turns out to be an extremely important feature of the theory in understanding its physical content and in constraining the form of interactions in it. Therefore, in this project I tried to focus on the physical implications that symmetry has on field theories and corresponding impacts on particle physics.
So in this project, I mainly studied the following topics:

- canonical quantization approach to quantum field theory
- field equations for different spins and interactions between fields
- principle of local gauge invariance and quantum electrodynamics
- discrete and approximate symmetries and CPT theorem

To begin with, in simple words, QFT is the language of elementary particle dynamics. Having already studied analytical mechanics, non-relativistic quantum mechanics, the theory of relativity and about classical fields namely gravitational and electromagnetic, we can proceed to learn the quantum theory of fields.

I thoroughly studied a first book of quantum field theory by Amitabha Lahiri and Palash B. Pal and the lecture notes (of Part III Mathematical Tripos, University of Cambridge) on the same subject by Dr. David Tong. I also went through all the lecture videos of the same course available on the web-page of the author. For reference, I followed an introductory text on QFT by Michael E. Peskin and Daniel V. Schroeder.

I started with free fields and learned the canonical quantization procedure. This gives an insight of vacuum energy (the cosmological constant) and the Casimir effect. I moved on to describe interactions between fields using the interaction picture. I studied Wick's theorem and Feynman diagrams, using them I could calculate scattering amplitudes of different processes in elementary particle physics e.g. scattering of combinations nucleons and mesons etc.

After this, I did the fermionic quantization of the Dirac field and observed the connection with spin-statistics theorem. In this part, I learned about spinor and
chiral representation, Dirac’s hole interpretation, Feynman propagators and Feynman rules for fermions.

Then, I arrived at the second and the most important half of the project “Symmetry”. I studied extensively about the different types of symmetries in QFTs and tried to give a good classification for them. The most significant part is gauge symmetry with the help of which we can couple a fermionic (matter) field to a Maxwell field (light) and provide a quantum theory of electromagnetic interactions i.e. quantum electrodynamics, QED for short. I calculated amplitudes of some scattering processes in QED using the Feynman rules and diagrams.

At this stage, I saw how important symmetries are in QFTs, how gauging is done using the principle of local gauge invariance (the realization of a global symmetry as a local symmetry) and the consequences it brings in the physics of fields theories. Apart from that, I studied the discrete symmetries in free and interacting fields of different spins also which are: parity, charge conjugation and time reversal; and the CPT theorem.

At the end of the project, winding up, I tried to familiarize myself with the ideas of approximate symmetries; the phenomenon of spontaneous breaking of a symmetry and Goldstone’s theorem. I also read about Higgs mechanism.

I plan to continue reading more and deeply on this subject of field theory and symmetry following those mentioned above and some more advanced texts and further my understanding. After this study/project, currently I have the following topics in mind to explore and work on:

- *Higgs mechanism*

- *Yang-Mills theory of non-Abelian gauge fields*

- *Standard electroweak theory*